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# An Overview of 2014 SBIR Phase I and Phase II Materials Structures for Extreme Environments

*Hung D. Nguyen, Gynelle C. Steele, and Jessica R. Morris*
*Glenn Research Center, Cleveland, Ohio*

November 2015

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## Abstract

NASA's Small Business Innovation Research (SBIR) program focuses on technological innovation by investing in development of innovative concepts and technologies to help NASA mission directorates address critical research needs for Agency programs.

This report highlights nine of the innovative SBIR 2014 Phase I and Phase II projects that emphasize one of NASA Glenn Research Center's six core competencies—Materials and Structures for Extreme Environments. The technologies cover a wide spectrum of applications such as high temperature environmental barrier coating systems, deployable space structures, solid oxide fuel cells, and self-lubricating hard coatings for extreme temperatures. Each featured technology describes an innovation, technical objective, and highlights NASA commercial and industrial applications.

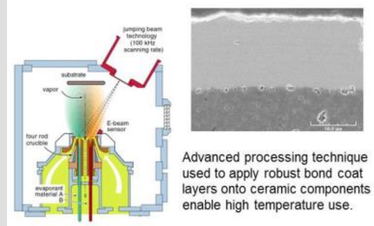
This report provides an opportunity for NASA engineers, researchers, and program managers to learn how NASA SBIR technologies could help their programs and projects, and lead to collaborations and partnerships between the small SBIR companies and NASA that would benefit both.

[1] Lewis' Educational and Research Collaborative Internship Project (LERCIP).

# Robust High Temperature Environmental Barrier Coating System

***For ceramic matrix composite gas turbine components using affordable processing approach***

This Phase I project demonstrates the use of advanced manufacturing techniques to enable the affordable application of multifunctional thermal/environmental barrier coatings (TBCs/EBCs) having enhanced resistance to high temperature combustion environments. Thermal/environmental barrier coatings (TBCs/EBCs) have potential for enhanced resistance to high temperature combustion environments. Current TBC/EBC systems are stable up to 2400 °F, but become unstable at 2700 °F. To improve the performance at these high temperatures, multi-layered T/EBC designs are proposed. To improve capability, a multiple layered T/EBC system will be employed using a physical vapor deposition based processing approach. This deposition approach enables improved coating adhesion and advanced coating, architectural, compositional, and microstructural control, as well as non-line-of-sight (NLOS) deposition. TheTBC/EBC bond coats will then be deposited onto gas turbine engine components for full high temperature capable systems. This work aids in incorporating Si-based ceramic components in gas turbine engines, thus reducing weight and increasing operating temperatures of the engines.



Advanced processing technique used to apply robust bond coat layers onto ceramic components to enable high temperature use.

## Phase I Objectives

- ► Demonstrate feasibility of using advanced plasma activation techniques
- ► Demonstrate scaled up processing approach
- ► Perform metallographic analysis, thermal cycle testing.

## Benefits

- ► Reduced fuel consumption
- ► Increased operating temperatures
- ► Improved turbine efficiency
- ► Robust bond coat protects component surface from ceramic recession
- ► Coats interior portions of components

## Applications

### NASA

- ► Coating for components of future aircraft engines that operate at high temperature, including:
  - o Turbine blades
  - o Combustion liners
  - o Exhaust components
  - o Gas turbine engines
- ► Increased turbine engine performance for the ARMD Subsonic Fixed Wing Project

### Commercial

- ► Reduced costs for coating onto commercial engine components
- ► Other functional coating systems such as:
  - o Thermal barrier coatings
  - o Wear- and corrosion-resistant coatings
  - o Thin film batteries
  - o Damping coatings

### Firm Contact

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Direct Vapor Technologies International, Inc.
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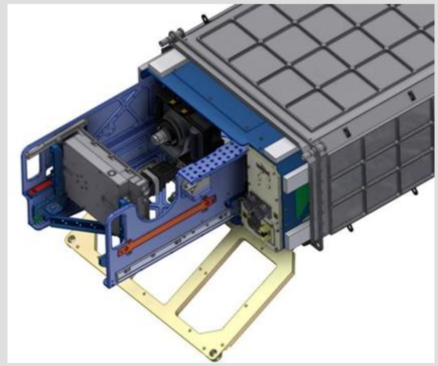
Charlottesville, VA, 22903-4605
PHONE: (434) 977-1405
**Proposal number: A3.07-8783**

# A Simple, Robust, Lightweight Microscopy and Sample Processing System for Scientific and Commercial Research on the International Space Station



## Phase I Objectives

- ► Defining requirements
- ► Building a prototype dynamic microscopy system
- ► Testing in a laboratory setting by real users under conditions worthy of a final TRL-5 designation

## Benefits

- ► High-throughput, lightweight microscopy system
- ► Novel-illuminator-condenser with no moving parts
- ► Fluid sample processing capabilities
- ► Remotely controlled translating stage using hollow slides
- ► High-definition color video camera
- ► Multiparameter image processing and analysis
- ► Expected to increase the level of interest in light microscopy experiments aboard the ISS

***A light-weight, user-friendly, algorithmically- or remotely-controlled microscope for easy-access light microscopy***

The need for high-quality microscopy in space is expected to intensify in colloid physics, particle suspensions, biomolecule crystal growth, and basic life sciences. An algorithmically- or remotely-controlled digital microscope coupled to high-throughput fluid sample processing and sample changing systems is proposed as a solution. The Techshot microscope is an easy-access light microscope consisting of a novel illuminator-condenser with no moving parts, fluid sample processing capabilities, a remotely controlled translating stage using hollow slides, a high-definition color video camera, and available multi-parameter image processing analysis. Its simplicity is expected to further increase interest in light microscopy experiments aboard the ISS.

## Applications

### NASA

- ► Use within the International Space Station—National Laboratory by NASA investigators

### Commercial

- ► Can be incorporated into other spaceflight service programs for government agencies
- ► Industrial research on the dynamics of colloids and particle suspensions found in food, cosmetic, paint, pharmaceutical, and composite industries

### Firm Contact

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Techshot, Inc.
7200 Highway 150
Greenville, IN, 47124-9515
PHONE: (812) 728-8136
FAX: (812) 923-9598
**Proposal number: H10.02-8875**

# Self-lubricating Hard Coatings for Extreme Environments

***Low-friction hard coatings for lubricating mechanical and tribological components***

This program will develop low friction hard coatings for lubricating mechanical and tribological components used for exploring Mars, the Moon, asteroids, comets, and other small bodies. This SBIR program will build on MesoCoat's extensive prior experience in developing dense, hard friction-free coatings.

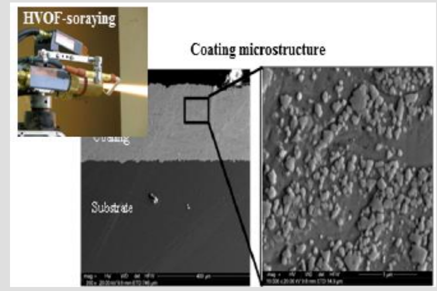
## Applications

**NASA**

- ► Rovers
- ► Motor and pump shaft and seals
- ► Deployable structures
- ► Latching mechanisms

**Commercial**

- ► Commercial aircraft engines
- ► Diesel and turbine engines
- ► Run-dry industrial linkage component applications
- ► Metal cutting and forming tools and dies
- ► Mining and excavation equipment
- ► Automotive components
- ► Agricultural equipment




## Phase I Objectives

- ► Verify that self-lubricating hardfacings can meet life and lubrication requirements of space exploration mechanisms
- ► Prepare nanocomposite self-lubricating cermet agglomerated powders
- ► Add additional encapsulants and additives to produce desired meso-structures in coatings
- ► Apply to substrates using HVOF thermal spray
- ► Evaluate run-dry friction and wear properties
- ► Analyze results in terms of composition, micro- and meso-structure, and coating method to guide future down-selection

## Benefits

- ► Provides wear resistance and lubrication in high temperatures and severe environments
- ► Nano-structured and meso-structured coatings that are compatible with steel, aluminum, and titanium
- ► Low-friction hard coatings for lubricating mechanical and tribological components for exploring lunar and Mars surfaces

### Firm Contact

Evelina Vogli
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**Proposal number: S4.04-8603**

# Development of Hermetic Sealing Glasses for Solid Oxide Fuel Cells

### *Producing seals with the goal of zero or minimal leak rates*

Sealing glasses, either rigid glass-ceramics or viscous, non---crystallizing compositions, will be developed  and sealing processes will be optimized based on NASA's solid oxide fuel cell (SOFC) designs. SOFC design constraints will guide compositional development, and these new compositions will then be used for long-term (500 hours) material compatibility tests under SOFC operational conditions. Prototype seals will then be produced and thermally cycled between room temperature and 850°C to test thermo-mechanical compatibility of the sealing material with SOFC components.

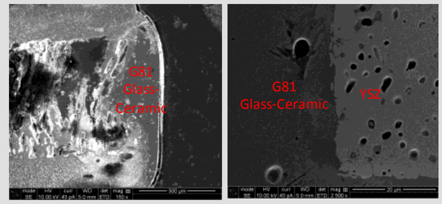
## Applications

**NASA**

- Reliable, thermally stable, hermetic sealing materials for SOFCs and SOEs
- High-efficiency power systems

**Commercial**

- Aid nation's SOFCs program meet its cost and performance targets
- Achieve reliable SOFC operation for extended operating life
- Enable fuel cell-based near-zero emission coal plants that reduce water requirements and capability of capturing 97% of carbon




Excellent wetting and bonding to YSZ

## Phase I Objectives

- Identify specific SOFC materials for sealing and determine specific operational conditions
- Test glass-ceramic seal and/or viscous glass seal with NASA specified materials and conditions
- Refine the glass compositions and processing parameters with the requisite thermal and physical properties
- Evaluate long-term thermal and chemical stability
- Conduct hermetic and thermal cycle tests

## Benefits

- Capable of thermal cycling under SOFC operational conditions (e.g., methane/oxygen)
- Thermally and chemically stable, thus further developing SOFCs as high-efficiency power system

**Firm Contact**

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MO-SCI Corporation
4040 Hy Point North
Rolla, MO, 65401-8277
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FAX: (573) 364-9589
**Proposal number: H8.01-9586**

# Simulating Nonlinear Dynamics of Deployable Space Structures

***Improved simulation of 3D nonlinear dynamics of future large solar array structure systems***

This project strengthens validated modeling analysis and simulation techniques by developing a vertical application to simulate the nonlinear dynamics of the various stages of deployable space structures. Modeling complex, flexible-body, nonlinear structures can be time consuming and prone to error. Existing nonlinear structural analysis simulation software does not effectively simulate structural assemblies with significant motion. This project will address the simulation problems by creating a custom vertical application for deployable space structures. The software will include a dynamic simulation of the rollup, deployment, and maneuvering operation of large solar array structures. Additionally, an active, nonlinear controller will be developed that will reduce roll-out solar array (ROSA) deflection during spacecraft maneuvers.

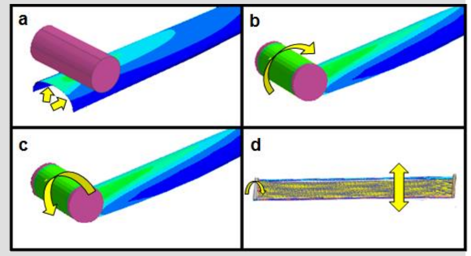
## Applications

### NASA

- Simulation of nonlinear dynamics of ROSA structures
- Software applications for deployable space structure market
- Solar array configurations
- Deployable antennas

### Commercial

- Software application for agencies that work with deployable space structures
- Deployable flaps and slats on aircraft




## Phase II Objectives

- Add capabilities to software developed in Phase I
- Improve integration of functions, including new support of the simulation of lanyards and tape strings
- Simulation of additional deployable space structures including antennas

## Benefits

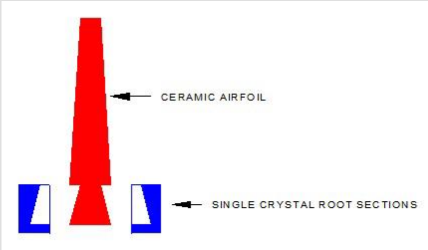
- Advanced simulation capabilities that are more efficient and require less specialized knowledge
- Reduced deflection of a ROSA during spacecraft maneuvers

### Firm Contact


Brant Ross
MotionPort LLC
473 South River Road, Suite 1-182
Saint George, UT, 84790-2150
PHONE: (435) 703-9195

**Proposal number: H5.02-9104**

# Improved Attachment Design for Ceramic Turbine Blades via Hybrid Concepts




### *A design that exploits the thermal expansion mismatch between CMCs and metals to solve the attachment issue*

This project proposes a hybrid metal-CMC turbine blade. A SiC/SiCCMC airfoil section will be bonded to a single crystal superalloy root section to mitigate risks associated with an all-CMC blade inserted in a superalloy disk. The bond between the CMC and single crystal will be primarily mechanical, and enhanced with clamping arising from thermal expansion mismatch. Two single crystal root sections will be bonded to each other using diffusion bonding and/or transient liquid phase bonding at temperatures near 2200°F.The single crystals will form a clam shell around the CMC. Upon cooling, the metal will shrink around the CMC spar to firmly clamp it. Single crystals will resist stress relaxation at an operating temperature of 1500°F, thus maintaining clamping loads for long lives.

## Applications

### NASA

- Reliable insertion for ceramic matrix composite blades into high temperature nickel alloy disks
- Enabling technology for meeting future goals of achieving SFC gains
- Turbo engine designs with CMC materials resulting in higher operating temperatures

### Commercial

- Aircraft engines
- Pratt and Whitney
- Rolls Royce would benefit from a hybrid blade attachment design

## Phase II Objectives

- Demonstrate the manufacturability of the single crystal clam shell clamped to a CMC spar
- Demonstrate the single-crystal clam shell's ability to maintain an interference fit on the CMC spar during operational conditions
- Determine if a compliant layer is required between the CMC spar and the single crystal clam shell

## Benefits

- Higher operating temperatures
- Reductions in required cooling
- Reductions in vehicle weight
- Increased durability and/or decreased weight of PM disks

### Firm Contact

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**Proposal number: A3.07-9772**

# Lightweight, Advanced Sorbent-based Device to Collect and Pressurize $CO_2$ from Martian Atmospheres

### *Development of a high-capacity, high-purity, regenerable $CO_2$ adsorbent*

Human exploration of Mars and unmanned sample return missions can benefit from use of propellants and life-support consumables produced from resources available on Mars. The first step of any in-situ propellant production is the acquisition of carbon dioxide from Mars's atmosphere and its compression for further chemical processing.

TDA Research Inc. has developed a compact, lightweight, advanced sorbent-based compressor to recover high-pressure, high-purity $CO_2$ from the Martian atmosphere. The system eliminates the need for a mechanical pump, increasing the reliability with relatively low power consumption. TDA's system uses a new, high capacity sorbent that selectively adsorbs $CO_2$ at 0.1 psia and regenerates by temperature swing, producing a continuous, high-purity $CO_2$ flow at pressure (>15 psia).

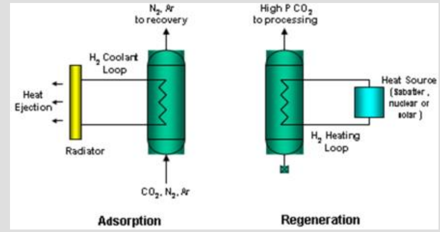
## Applications

### NASA

- ► Lightweight, compact, and energy efficient adsorbent based solid-state $CO_2$ compressor system to collect and pressurize $CO_2$ from the Martian atmosphere
- ► $CO_2$ control system for commercial spacecraft cabin air revitalization and space suits

### Commercial

- ► Removal of $CO_2$ emissions from the coal-fired power plants
- ► Removal of $CO_2$ from
  - o Biogas
  - o Natural gas
  - o Water-gas-shift reaction in hydrogen manufacturing




## Phase II Objectives

- ► Develop a high capacity, regenerable $CO_2$ adsorbent that maintains its $CO_2$ capacity and mechanical integrity over extended adsorption/desorption cycles
- ► Optimize the sorbent formulation
- ► Conduct at least 100 complete adsorption/regeneration cycles for the best sorbent formulation
- ► Carry out a design of the adsorbent-based $CO_2$ compressor
- ► Demonstrate the technical feasibility of the concept
- ► Quantify the logistics savings

## Benefits

- ► Eliminates the need for a mechanical pump
- ► Increases the reliability with relatively low power consumption

### Firm Contact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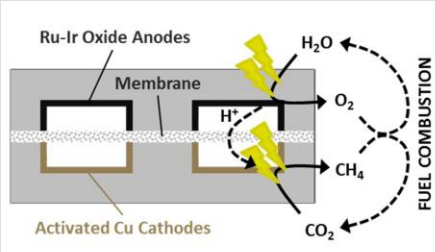
Wheat Ridge, CO, 80033-1916
PHONE: (303) 422-7819
FAX: (303) 422-7763

**Proposal number: H1.01-9408**

# Microfluidic System for $CO_2$ Reduction to Hydrocarbons in Microgravity




***Low-cost fabrication of high-efficiency microchannel-plate reactors for the electrocatalytic reduction of $CO_2$ to $CH_4$***

Electrocatalytic reduction of carbon dioxide to methane and other hydrocarbons (HC) will be demonstrated based on the etching of microchannel electrodes and copper electrodeposition on the cathodes. The copper electrocatalytic efficiency will be enhanced via oxide reduction. A high channel density will give high active area in compact form factor while avoiding complications of packed-bed reactors. Ionic liquids (ILs) will give advantages such as low evaporative loss, high $CO_2$ and low HC solubility, and electrochemical inertness. The challenge of gas-liquid separations in microgravity will be addressed through a novel centripetal application of an established spiral-channel microfluidic concept. The system includes: 1) absorber to getter gaseous $CO_2$ using an IL electrolyte, 2) microfluidic electroreactor to convert $CO_2$ to HC with $O_2$ as by-product, and 3) spiral-channel gas-liquid separator to remove HC and $O_2$ from the IL for recycling to the absorber.

## Applications

### NASA

- Centripetal microchannel separators for gas-liquid separations in microgravity
- In-situ generation of hydrocarbon fuels from $CO_2$ sourced from crew exhalation gases or the Martian atmosphere
- Compact form factor of stackable-plate will integrate readily into NASA space vehicles

### Commercial

- Highly efficient chemical reactors
- Efficient, low-power, in-situ conversion of carbon dioxide to methane
- Reduction in anthropogenic greenhouse gas emissions (including carbon dioxide)

## Phase II Objectives

- Demonstrate and develop a technology for production of stackable-plate microchannel reactor-separator units for $CO_2$ reduction to hydrocarbons to serve as a means for in-situ generation of fuel during space missions
- Demonstrate the control of copper deposit thickness, structure, and conformity
- Execute copper layer oxide reduction activation process
- Demonstrate electrocatalytic activity of activated copper layers
- Evaluate the feasibility in terms of thermal, electrical, and economic considerations
- Develop a simulation and modeling argument for feasibility of centripetal separation concept

## Benefits

- Robust, high-efficiency microreactor systems for conversion of $CO_2$ to $CH_4$

### Firm Contact

E. Jennings Taylor
Faraday Technology, Inc
315 Huls Drive
Englewood, OH, 45315-8983
PHONE: (937) 836-7749
FAX: (937) 836-9498
**Proposal number: H1.01-9409**

# Cavitation Peening of Aerospace Bearings

***Using bubbles to strengthen metals***

High-value bearings are critical for safety, reliability, cost, and performance of modern aircraft. A typical passenger jet has 100 to 175 high-value bearings, each costing $2,500 to $50,000. Ormond LLC has developed a process called cavitation peening that has been shown to enhance bearing life which in turn reduces cost and frequency of bearing replacement. The process imparts deep, high magnitude residual stresses through use of ultra-high pressure water jets to generate intense clouds of cavitation bubbles that collapse on the work piece generating shock waves that cold work the material. The process uses no particles, and thus produces no waste and adds no weight to the part, all while enhancing bearing life, reliability, and performance.

## Applications

### NASA

- Aircraft gas turbines
- Rotating components where weight or power consumption is an issue, such as
  - Motors
  - Rotors
  - Pumps
  - Wheels
- New bearing materials and non-bearing applications, such as
  - Airframe structures
  - Gears
  - Drivetrain components

### Commercial

- Automobile fuel economy
- Wind turbine power generation
- Aircraft engine efficiency and reliability
- Manufacturing machinery reliability
- Aluminum airframes
- Carburized gears
- Titanium rotors and disks
- Steel structures

## Phase II Objectives

- Demonstrate the ability to generate high magnitude deep residual stress in different kinds of bearing elements and different bearing materials with cavitation peening
- Characterize the non-residual stress effects of cavitation peening
- Quantify rolling contact fatigue life improvement for cavitation-peened bearing components and full bearing assemblies
- Demonstrate the stability of the cavitation peening effects over load cycles and temperature cycles to simulate aircraft environments

## Benefits

- 100% fatigue improvement
- Enhances bearing life, reliability, and performance
- No particles are used
- No waste created from process
- Adds no weight to components
- Reduces costs

### Firm Contact

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FAX: (253) 852-6940
**Proposal number: A3.07-9218**